Response to Reviewers for EGUSPHERE-2026-1017

We would like to express my sincere gratitude to both reviewers for their thoughtful and constructive feedback and the Editor for considering the original manuscript. We offer our response with a number of substantive changes that remedy the editor and Reviewers' comments and concerns. We have made substantive changes to the manuscript in response to each Reviewer comment, which can be found below. We believe that the feedback we received and the new results and discussion that prompted have substantially improved the manuscript.

Reviewer comments are shown in plain text**. Author responses are shown in bold text. Quotations from the revised manuscript are shown in *bold italics*. A bibliography for references cited is at the end of the document. <u>The revised manuscript and the version of tracked changes will be uploaded with the editor's decision</u> about the further handling of the manuscript.**

Reviewer(s)' comments to Authors

Reviewer 2

GENERAL REMARKS

In their manuscript "Teleconnection processes linking snow cover variability over western Siberia to enhanced early-winter cold waves in South Korea" the authors try to connect cold waves identified in South Korean in-situ AWS data with snow cover changes in Siberia. In general, I find the manuscript to fit the scope of The Cryosphere. I like the relatively straight forward thought structure and did not find anything that would require a major revision. Nevertheless, I have two general remarks that I would like to see addressed.

: We sincerely thank the Reviewer #2 for the careful evaluation and positive feedback about our manuscript. We would also like to appreciate the kind suggestions. Please find our response below regarding about the reviewer's comments and suggestions.

1) Causation vs correlation
I see this again and again, and I am a big supporter of statistical analyses, but please make sure that your language does not communicate causality behind your analysis. You found a statistical, linear link between certain components of the Earth System. That is great and useful and interesting, but it does not automatically mean that this is a causal relationship. Just be aware of that.

: Thank you for this important comment. We also agree that our statistical analyses, especially focusing on correlation and linear regression methods cannot explain the causality between the climate variables. In the revised manuscript, we have revised the related lines that might cause this misunderstanding.

L394: ***It is noteworthy that the anticyclonic anomaly identified in this study is similar to the atmospheric responses associated with Barents-Kara Sea (BKS) sea ice loss discussed in previous studies. Reduced BKS sea ice is known to be linked with a northward shift of cyclone tracks (Inoue et al., 2012), a stationary Rossby wave response to anomalous surface heating over the Arctic Ocean (Honda et al., 2009), and a shift toward the negative phase of the Arctic Oscillation (Nakamura et al., 2015). Although the detailed mechanisms differed among these studies, they commonly showed similar enhanced anticyclonic circulation patterns over Siberia and subsequent cooling over East Asia. Therefore, the circulation pattern identified in this study may be partly similar to the atmospheric response to BKS sea ice loss. However, our results indicate that thermodynamic changes associated with reduced SC over the western Siberia may also contribute to the anticyclonic anomaly.***

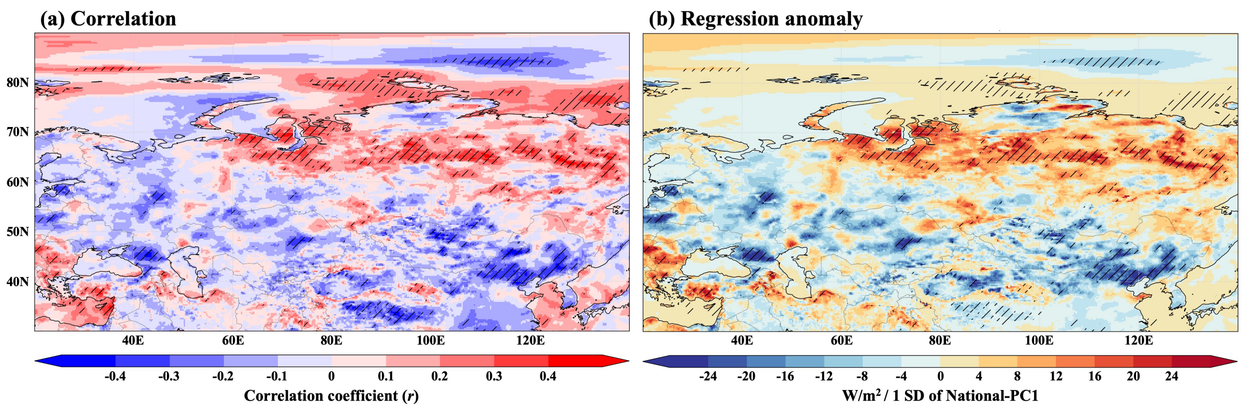
As western Siberian SC and BKS sea ice are geographically close and may be associated with similar atmospheric circulation patterns, their variability may not be fully independent. We therefore examined their respective relationships with December cold wave variability in South Korea. The results showed that October Western Siberian SC showed relatively stronger correlation with December cold wave variability than October BKS sea ice concentration (Supplementary Figure S5). In addition, the relationship between western Siberian SC and December atmospheric circulation remained statistically significant even after controlling for the linear influence of BKS sea ice concentration using partial correlation analysis (Supplementary Table S1). The results indicate that western Siberian SC is associated with December cold wave variability even after accounting for the variability shared with BKS sea ice concentration. However, these analyses cannot fully separate the effects of SC reduction and sea ice loss or determine the causal relationship between them. Further studies using nonlinear causality analysis and climate model experiments are therefore needed to clarify the individual and combined effects of western Siberian SC and BKS sea ice loss on early-winter cold waves in South Korea.

2) The chicken vs the egg problem
One point you did not address, is the origin behind the snow cover anomalies. What is the forcing behind those anomalies? To me it looks suspiciously like they are triggered by Barents-Kara Sea Ice variability, which then again is maybe triggered by SST anomalies (looking at correlations with SST anomalies would be great anyways). I think you need to invest at least a little bit of time in the discussion part to address this. Or if you want to invest a bit more time, you could do a proper data analysis to investigate the co-variability with sea ice. Also I find it strange that you focus so much on this one region of significant correlations. But I specify that below.

: Thank you for your comment. About the relationship between the snow cover in west Siberia and Barents-Kara Sea Ice variability (SIC-BKS), both of the reviewers has pointed out to investigate the co-variability. We have conducted additional statistical analyses below to support our physical process.

We performed a regression analysis between the National-PC1 time series and October turbulent heat flux from ERA5, extended over both land and ocean, and calculated the flux anomaly associated with one standard deviation of National-PC1.

The results reveal that statistically significant positive flux anomalies are more spatially coherent and of greater magnitude over the western Siberian land surface than over the BKS. Specifically, the regression analysis shows upward turbulent heat flux anomalies exceeding 20 W/m² per 1 SD of National-PC1 over inland western Siberia, whereas anomalies over the BKS Sea remain less than 4 W/m² per 1 SD of National-PC1. Although this analysis does not allow us to fully disentangle the interacting effects of snow cover reduction and sea ice loss, but it provides quantitative evidence that the snow cover reduction in western Siberian is more strongly associated with December cold-wave variability in South Korea than sea ice variability in the BKS.



Supplementary Figure S5. *(a) Correlation analysis between National-PC1 and October ERA5 upward turbulent heat flux. (b) Regression anomaly of October ERA5 upward turbulent heat flux with respect to 1 standard deviation of National-PC1. Hatched areas indicate regions statistically significant at the 90% confidence level.*

We also performed partial correlation analysis. For this, we first calculated area-averaged October ERA5-Land snow cover over western Siberia (55–90° E, 55–70° N, SC-WS) and ERA5 sea-ice concentration over the Barents–Kara Seas (40–100° E, 70–85° N, SIC-BKS). Using the original and non-detrended time series, respectively, October SC-WS showed a statistically significant negative correlation with the National-PC1 time series ($r = -0.371$, $p < 0.05$). October SIC-BKS also showed a negative correlation with National-PC1, but the strength was weaker ($r = -0.268$, $p < 0.10$).

Because October SC-WS and SIC-BKS may covary, we further conducted a partial correlation analysis to determine whether the relationship between SC-WS and December atmospheric circulation remained after statistically controlling for SIC-BKS. For this analysis, linear trends were removed from October SC-WS, October SIC-BKS, and December 500 hPa geopotential height (Z500) before the calculations. December Z500 was spatially averaged over the region encompassing the western Siberian anticyclonic anomaly

shown in Figure 6 (55–100° E, 55–75° N). Specifically, detrended SC-WS and detrended Z500 were separately regressed onto detrended SIC-BKS, and the partial correlation was calculated between the residuals from the two regressions.

The detrended October SC-WS and SIC-BKS time series were significantly correlated (r = 0.350, $p < 0.05$). However, after controlling for detrended October SIC-BKS, the partial correlation between detrended October SC-WS and detrended December Z500 remained significant ($r = -0.280$, $p < 0.10$). This value was similar to the correlation before controlling for SIC-BKS ($r = -0.296$, $p < 0.05$), indicating that accounting for SIC-BKS variability only slightly weakened the relationship between SC-WS and Z500.

These results show that the relationship between October western Siberian SC and December Z500 remains after statistically accounting for BKS SIC. We have therefore revised the manuscript to clarify that western Siberian SC variability is associated with December atmospheric circulation beyond the linear variability shared with nearby SIC.

Supplementary Table S1. *Correlation and partial-correlation analyses among October western Siberian snow cover (SC-WS), Barents–Kara Sea sea ice concentration (SIC-BKS), December 500 hPa geopotential height (Z500), and the December National-PC1 time series.*

Analysis	**Variables**	**Controlled variable**	**Data treatment**	***r***	**p-value**
Pearson correlation	October SC-WS vs National-PC1	—	Original time series	−0.371	**
Pearson correlation	October SIC-BK vs National-PC1	—	Original time series	−0.268	*
Pearson correlation	October SC-WS vs October SIC-BK	—	Linearly detrended	0.350	**
Pearson correlation	October SC vs December Z500	—	Linearly detrended	−0.296	**
Pearson correlation	October SIC vs December Z500	—	Linearly detrended	−0.101	*n.s.*
Partial correlation	October SC vs December Z500	October SIC	All variables linearly detrended	−0.280	*

$^{**}p < 0.05$, $^{*}p < 0.1$, n.s. $p > 0.1$

SPECIFIC REMARKS

L30: I guess severe cold waves have been documented for more than a hundred years now.
: We wanted to emphasize the recent extreme cold waves which have happened under a warming climate. We have revised our line as follows.
"Under a warming climate, severe cold wave events have also been recently more documented across…"

Table1: Is "morning minimum" the same as "daily minimum" ?
: Yes. It was revised to "*daily minimum*".

L125: This is confusing. 1973 to 2023 is covering more than 10 years.
: Thank you for the comment. To remove the confusion, we have revised the sentence as follows.

"First, the climatological normals required for 'Criterion 1' cannot be reliably calculated, covering the full study period of 1978-2024."

L248: Why the focus on western Siberia? The motivation behind this should be explained here (again).
: As mentioned in the introduction section, few of the studies regarding about Siberian snow cover (SC) acknowledged that dipole pattern has been observed across Siberia; increasing SC pattern in east Siberia and decreasing SC pattern in west Siberia. However, most of the studies that combined Siberian SC with East Asia winter cold waves only focused on east Siberia, which drew our attention about the role of decreasing SC pattern of west Siberia.
In L246, we added
L246: ***Because most previous studies linking Siberian SC variability to winter cold waves in East Asia have focused primarily on eastern Siberia, we investigated the role of western Siberian SC variability, which has received comparatively less attention.***

L272: How do you infer that the impact with November SC is low when the correlation is significant?
L275: See above, I find your justification for that very weak.
: In Fig 4f, For the western Siberia, the area that's showing statistically significant is very localized. For eastern Siberia, the average SC during November is almost 100%, as shown in Fig S3c. As a result, we have judged that the statistically negative correlation in east Siberia is due to statistical bias with very low variability. The area that has white (or no) contour over central to east Siberia means that the variability of SC is 0 (SC 100% during the study period).

We revised L273 as
L273: ***…(Figure 4f). However, we determined that this statistically significant negative correlation has been caused by statistical bias, as SC in these regions approaches nearly 100% in November and shows minimal interannual variability (Figure S3c) Additionally, ...***

L281: Well, this seems a bit like cherry picking. What about all the other regions and seasons with significant correlations?
: As noted above, we focused specifically on western Siberia because relatively few studies have examined the relationship between SC variability in this region and winter cold waves in East Asia. October is also a key transition period, during which the land surface over western Siberia changes from bare ground or vegetation to snow-covered conditions, while SC undergoes a pronounced decline in some areas (Fig. S3). In addition, October SC over western Siberia exhibited both a statistically significant decreasing trend and a statistically significant negative correlation with National-PC1. Based on these results, we focused primarily on October SC variability over western Siberia.

L302: This particular region is adjacent to the Barents-Kara Sea, which experienced very strong sea ice loss in the last decades. Is this just the heating from the open seas that influence that continental region? You also see that in Figure 6.

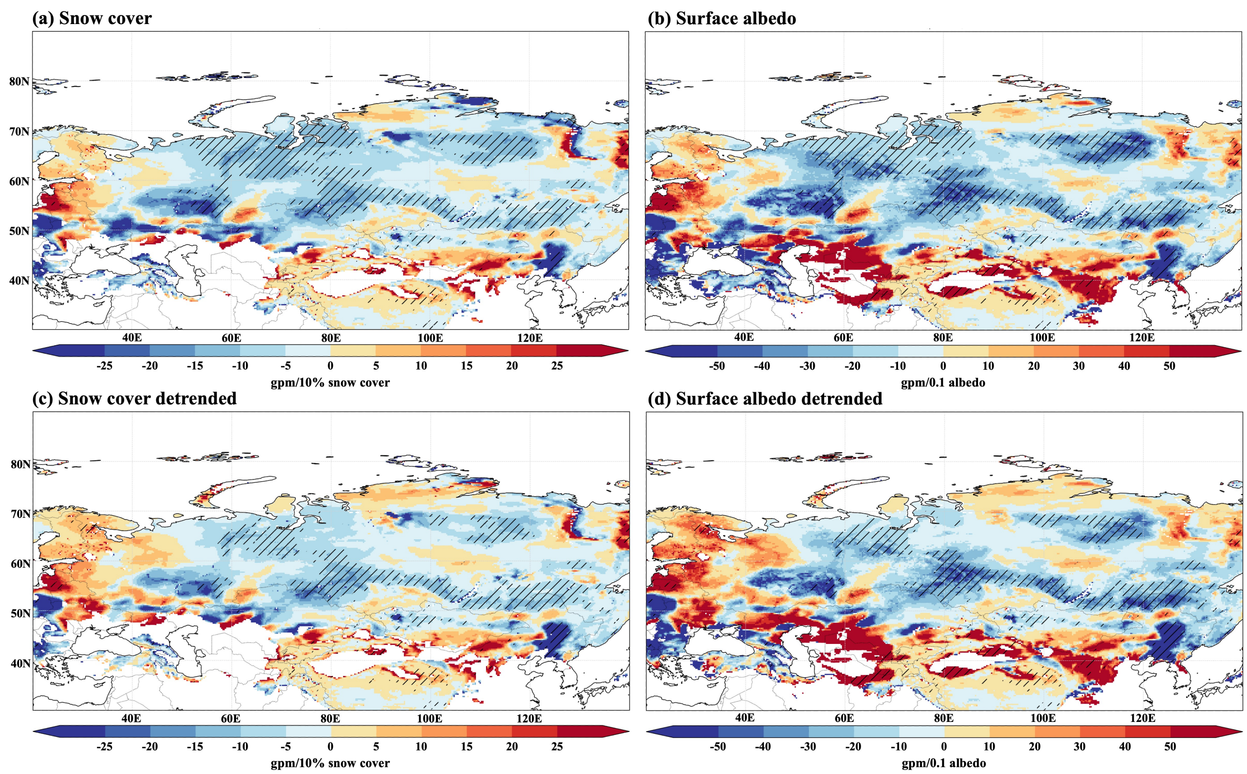
: To support our hypothesis, we've added additional analyses, including regression anomaly of turbulent heat flux with respect to one standard deviation of the National-PC1 time series. We also added partial correlation analysis in the revised manuscript.

L343: This is a nice finding! I have not seen those numbers before!

: Thank you!

Figure 8: December 500hPa GPH where? I would keep the same color scale for a) and c)

: It is grid-grid linear regression analysis. We unified the color bar accordingly as follow.



L354: I would rephrase "linked" to "statistically linked".

L363: I would rephrase "linked" to "statistically linked".

: Changed accordingly.

References

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Nakamura, T., Yamazaki, K., Iwamoto, K., Honda, M., Miyoshi, Y., Ogawa, Y., Tomikawa, Y., and Ukita, J.: A negative phase shift of the winter AO/NAO due to the recent Arctic sea-ice reduction in late autumn, J. Geophys. Res.-Atmos., 120, 3209–3227, https://doi.org/10.1002/2014JD022848, 2015.